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Laser Ignition Testing of Two-Piece Tank Ammunition For Advanced Tank Cannon System (ATACS)

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In this paper, new results on the development of a laser-based ignition system for ATACS will be presented. Full scale testing of a multipoint ignition system in a large caliber gun ballistics simulator are in progress. A Nd:Glass laser is used to initiate a vented igniter tube containing blackpowder at multiple locations and a booster charge of blackpowder at the interface. The results of pressure-time data and high-speed photography show that both ammunition components ignite within a time delay of less than 1 ms and that flamespread was uniform throughout the propellant bed. Blackpowder classifications, the number of ignition points and locations, and laser parameters such as energy and pulse duration will be varied to optimize performance of the system. The experimental results from parametric investigations of the direct laser-based ignition of the propellant (JA2) will also be presented. Quantitative measurement of the relationships between laser energy, laser pulse duration, and percent surface irradiation on ignition delay and ignition threshold have been made. The effect of molecular oxygen concentration on ignition threshold in solid propellant initiation has also been determined.

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1. INTRODUCTION

The LIGHT (Laser Ignition in Guns, Howitzers and Tanks) Program was established at the U.S. Army Research Laboratory (ARL), Aberdeen Proving Ground, MD, as a result of an ignition concept which was discovered at ARL called "resonance laser ignition" (Forch and Miziolek 1987, 1986, 1991; Forch, Morris, and Miziolek 1990). The attractive feature of this ignition source lies in the efficiency of the process which may allow for the development of small low-energy lasers to be used as igniters for energetic solid materials such as gun propellants. A laser source which is tuned to absorption transitions in solid materials or in pyrolysis gas produced at the solid-gas interface could lead to efficient, low-energy ignition thresholds. Furthermore, the ability to directly ignite propellant beds could lead to the elimination of primers and igniters from the ignition train which would dramatically minimize vulnerability, simplify the ignition train, and facilitate the ignition of insensitive munitions which are inherently difficult to ignite. Within the LIGHT Program, laser ignition has been categorized into two regimes—direct and indirect ignition. The direct laser ignition concepts focus on initiation of propellant beds via the interaction of laser light with the charge. Indirect laser ignition involves the removal of current primers and igniter material from the ignition train in their present configuration within the munition. The laser light is first transmitted to a sensitizer which is a small quantity of energetic material which then transfers the ignition stimulus to the propellant bed. Both laser ignition concepts involve the transfer of laser radiation into the gun through the use of optical fibers. Conventional propellant ignition systems use pyrotechnics and primary explosives which are impact initiated or electrically initiated to transfer energy to the propellant. In these configurations, simultaneous (isochronic) initiation and uniform flamespreading within the propellant may not be efficiently controlled such that combustion instabilities which lead to undesirable pressure oscillations or differentials can result. However, multipoint laser ignition through optical fiber networks have the potential to improve flamespreading characteristics through isochronic ignition and also to substantially reduce pressure waves. Additional advantages of a laser-based ignition system include improved system reliability, simplicity, and safety.

There are many important characteristics of the laser which much be addressed. These laser parameters include energy, power density, pulse length, wavelength, and repetition rate. Lasers which we have examined as ignition sources include rare-gas discharge lasers (excimers), CO_2 lasers, solid-state lasers such as Nd:YAG or Nd:glass, and small diode lasers. Excimer lasers are convenient sources of ultraviolet light (UV) which can be delivered at high repetition rates. Most energetic materials used in gun propulsion absorb well in the UV; however, the pulse length of these lasers (nanoseconds) is too short for reliable initiation. The high peak-powers generated by these lasers tend to cause ablation (blow-off) rather than ignition of the energetic material. In addition, the UV wavelengths produced by these lasers are not readily transmitted through optical fiber material and/or can damage the input coupler ends of the fibers. CO_2 lasers can readily generate high-energy pulses which can easily ignite energetic materials; however, the laser wavelength it produces (ca. 10.6 μm) also cannot be readily transmitted through optical fibers. Germanium fibers have been developed which will readily transmit this wavelength, but are very brittle, expensive, and cannot be manufactured in lengths suitable for gun applications. There are many other types of lasers which may serve as candidate igniters, however, a particularly attractive laser source is the solid-state laser based upon the Nd^{+3} ion. Generic lasers of this type are the Nd:YAG and Nd:glass which operate near 1.06 μm and 1.05 μm, respectively. These laser systems can be made very small (pyro-type), rugged, reliable, long-lived, and inexpensive. Laser radiation near 1 μm can readily be transmitted through very durable and inexpensive fused silica optical fibers over great distances with negligible loss. These lasers can operate in continuous mode or produce picosecond to millisecond pulses. This laser waveleng. .s also readily transmitted through sapphire breech window material. The Nd:glass laser has been used extensively as an ignition source within the LIGHT Program as a result of these attributes. Laser ignition sources may be mounted c. . external hardware at the gun mount or the laser may be directly attached to the gun breech. In either scenario, the laser must be sufficiently sturdy to survive the high-energy gun recoil forces. The laser must also use fail-arm-safe electronics to both alleviate unwanted firings and serve as an integrity verification of the optical ignition train.

This report describes the progress made in the development of a laser-based ignition system for the Advanced Tank Cannon System (ATACS) which consists of a two-piece ammunition. The incorporation of multicomponent ammunition in the propelling charge introduces interfaces which can interfere with reliable flamespreading characteristics in the combustion event. Interfaces which inhibit rapid flamespread within the propellant bed can lead to localized ignition which in turn may produce pressure differentials between the charge and projectile base. Interior ballistics calculations performed at ARL have shown that simultaneous ignition of multicomponent ammunition such as the two-piece tank round can enhance flamespreading characteristics and minimize the probability of gun failure. Therefore, an ignition system which utilizes a laser and a three-point optical fiber network has been developed and tested in a full-scale ballistics simulator. Detailed experimental investigations on the laser multipoint ignition of blackpowder, ball powder, clean-burning igniter (CBI), and JA2 propellant have been performed and will be described.

2. EXPERIMENTAL/PROCEDURE

There are numerous diagnostic lasers available to probe the ignition and combustion laboratory such as a Nd:YAG-Dye laser system which produces tunable laser light. Two high-energy Laser Photonics Nd:glass lasers serve as ignition sources. These lasers are variable energy (up to 30-J laser energy/pulse) and can generate pulse widths (using a pulse-forming network) from 100 μs to 10 ms. Diagnostics equipment includes optical multichannel analyzers, spectrometers, pressure sensors, digital scopes, and other high-speed image processing equipment. The beam diameter is 6.35 mm and divergence is 3–4 mrad. The calculated diameter of the laser beam at the focus of this laser vaiied from 300–500 μm, depending on the focal length of the lens used in either a pyrolysis or laser ignition experiment. This laser beam was focused into a single 300-cm length, 1-mm diameter cladded, solid-core fused silica optical fiber or into an optical fiber bundle with a 9-way split which gave ca. 1–2 J laser energy at the end of each SMA connector. The pulse energy was measured with a Scientech volume-absorbing disc calorimeter Model No. 38-0103 and analog meter.

In the JA2 direct ignition experiments, the propellant grains were mounted on a high-precision motion stage (a stack of three Daedal Series 100000 linear micropositioners and one Daedal Series 20000, 5-in rotary table) with four degrees of control (X, Y, Z, H). The translational stages each provide 4 inches of travel with a translational accuracy (straight and positional) of +/−5.0 × 10^{-5} in/in of travel and bidirectional repeatability of 5.0 × 10^{-5} in. The rotational stage provides angular repeatability of 0.2 arc/min with an accuracy of 3.0 arc/min. Each stage is driven by a stepper motor, with microstepping controlled by a Epson Model Plus microcomputer. Time sequencing of the two lasers was accomplished using a high- precision (+/−10 ps) digital delay generator (Stanford Research Systems, Model No. DG 535) which was triggered with the amplified signal from a high-speed pin-photodiode. A remote control outlet at the long-pulse laser generates a TTL trigger pulse when the laser fires, which can trigger another source or it accepts a similar TTL pulse for firing by an external trigger. The experimental set-up for the small-scale and full-scale ballistic simulators will be described later.

3. RESULTS AND DISCUSSION

3.1 <u>Blackpowder Ignition</u>. Blackpowder can be ignited easily with a laser over a wide range of energies and pulse durations. Laser ignition of blackpowder has been investigated previously by others (Ostrowski and Grant 1981). The investigations described in this work were performed using two

Nd:Glass lasers which can deliver up to 30 J of energy from pulses which can be varied from 150 μs to 10 ms. The blackpowder samples (Class 1, 3, 5) consisted of loose granules which were ignited at atmospheric pressure. The blackpowder was contained in bag material. An investigation of the interaction of the laser beam with the blackpowder bag material gave no evidence of ignition whatsoever, however, the weaving of the bag material was loose enough to readily allow for laser transmission though the material. The criterion for ignition was a single laser pulse which resulted in sustained ignition and complete combustion which consumed the entire sample. If the sample did not ignite, then it was discarded and replaced with an identical sample. A second laser shot into a previously irradiated sample showed that the first laser pyrolyzed the material which produced new chemical products with reactivities that differed from the original sample. This always resulted in a lower ignition threshold. A similar behavior was also observed in solid propellant direct ignition. A sapphire window was inserted into the laser beam path in order to split off 5% of the radiation to trigger detection electronics. A mylar window was also inserted into the laser beam optical path. Both of these windows are optical interfaces through which the laser beam must be transmitted in the ATACS ignition system, as will be described later. The transmissivity of a mylar window was also investigated. Detailed experimentation has shown that regardless of the laser pulse duration (2–10 ms), 70% of the laser was transmitted through with no damage to the mylar in 20 repeated shots; 30% of the laser beam was absorbed and/or scattered. It is interesting to note that the window was not burned or charred as a result of laser transmission.

A detailed investigation of the laser parameters required to ignite small blackpowder samples (up to 28 g) were performed. An electronic pre-trigger signal from the laser triggered the sweep of a high-speed digital oscilloscope. Two high-speed photodiodes observed the ignition event. The first photodiode was optically shielded and insulated to observe light emission other than that which resulted from the laser. The second photodiode captured light emission from the blackpowder ignition. The laser pulses were characterized by having a Gaussian-type spatial intensity distribution across beam measured from burn paper and/or spatially with a photomultiplier/scanning monochromator. Mode structure can indeed vary spatially from pulse-to-pulse as a result of thermally induced distortions (phonon modes) within the rod as it is heated during repetitive firings. The temporal profiles of the laser beam vary dramatically as the laser pulse lengths increase from the microsecond to millisecond time regime. The lasers employed in this work utilize a pulse-forming network to alter flashlamp discharge to achieve longer pulse lengths. Laser pulses in the 150 μs to 1.0 ms time regime yield a somewhat distorted Gaussian profile, while the temporal profile of laser pulses >1.0 ms approach a square wave.

A parametric investigation of the laser pulse duration, laser energy, and ignition delay on the ignition of blackpowder revealed several reproducible trends. The first signals that were observed was laser scatter followed by light emission at longer times from the complete combustion of the samples. A plot of the ignition delay time relative to the leading edge of the laser pulse vs. pulse length is presented in Figure 1a. Each data point is represents the average of three independent measurements with an error of ~10% as obtained from the standard deviation of the mean. Time to ignition was measured from digital oscilloscope traces, relative to the laser pulse, as the point where the baseline slope changed more than 5%. It was found that shorter length laser pulses, at constant energy, resulted in smaller ignition delays relative to the longer laser pulses. This has been attributed to heat loss through thermal diffusion in the material when an identical quantity of energy is delivered to the surface in a long laser pulse as compared to a much shorter pulse. Conversely, it was found that the ignition threshold for identical samples decreased with longer laser pulses as is depicted in Figure 1b (i.e., longer laser pulses required less energy for ignition than shorter laser pulses). Furthermore, there was a near linear dependence of the laser pulse length on ignition energy threshold. It was also found that if the laser beam was tightly focused, then the rate of energy input into the material could not compete with thermal diffusion into the material; therefore, ignition delay times became much longer or sustained combustion was not achieved because of surface ablation. A key feature of this work which is readily apparent is that, although at constant energy longer pulses have a longer ignition delay, simply increasing the energy results in minimal ignition delays. For example, for a 5-ms, 2-J laser pulse which ignited a small 1-g sample of blackpowder, an ignition delay of 7 ms was measured from baseline extrapolation of an intensity-time plot. However, doubling the laser energy to 4 J under otherwise identical experimental conditions shows that the blackpowder begins to burn during the laser pulse with essentially no delay. This observation is further quantified by plotting the ignition delay for identical blackpowder samples using a 2-ms laser pulse at the ignition threshold as a function of laser energy (Figure 1c). A linear dependence of the ignition delay on laser energy was observed. Therefore, a plausible method of minimizing ignition delay times for blackpowder essentially reduces to a compromise or trade-off between long laser pulses, which give lower ignition energy thresholds and short laser pulses which give short ignition delays, but higher ignition thresholds.

A series of experiments using an optical fiber network for multipoint ignition of blackpowder were performed. The Laser Photonics system has a provision for connection to a 9-way optical splitter which is interfaced to the laser through standard SMA-type connectors. The laser beam was focused into the bundle and about 2 J of laser energy were measured at the end of each 5-m optical cable. The laser

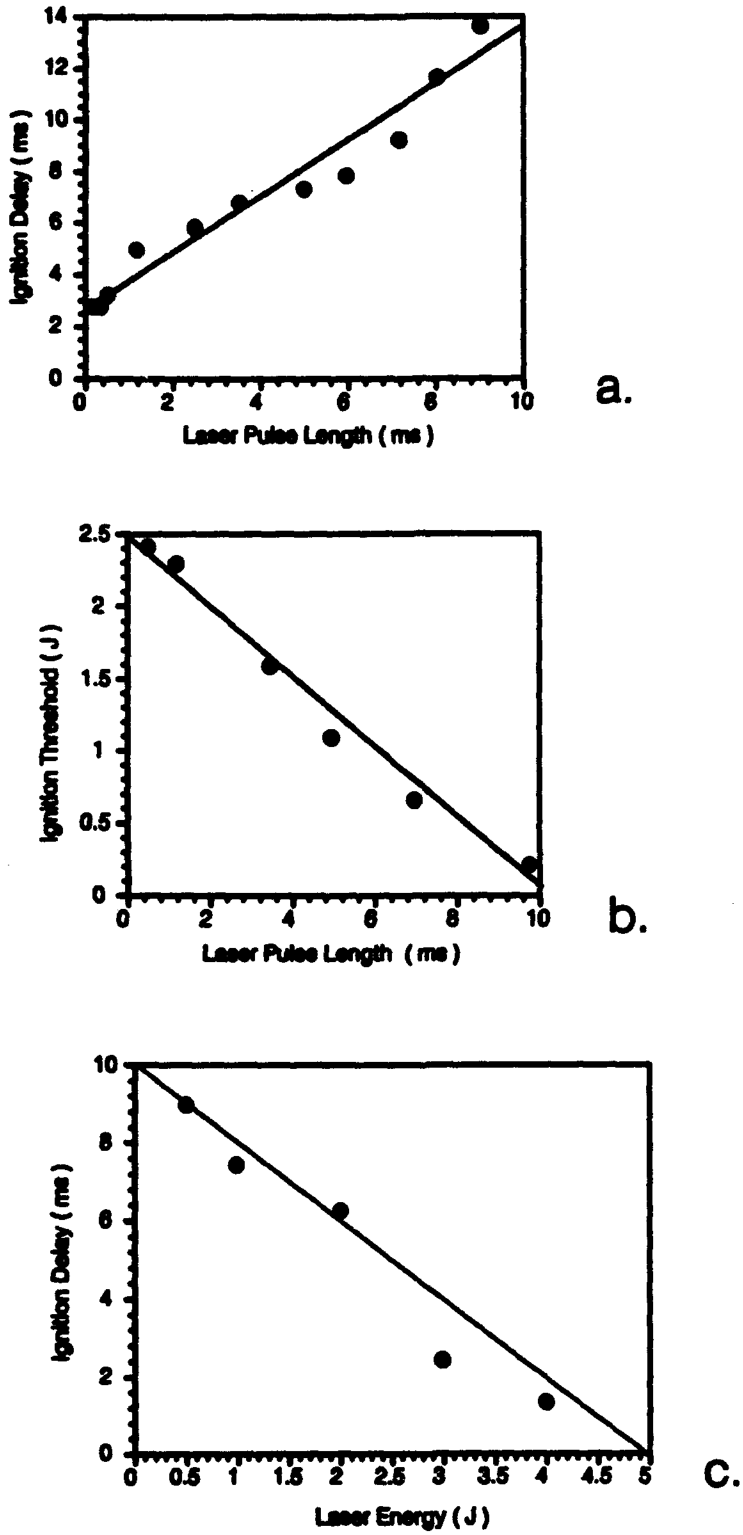

Figure 1. Results of quantitative ignition experiment measurements of the laser ignition of blackpowder.

ignition data for the initiation of six blackpowder igniters showed that all samples ignited within < 0.5 ms of each other, and that the samples were entirely consumed.

The ignition of alternate igniter materials such as ball powder and clean-burning igniter material was also investigated. These materials have the advantage of leaving much less carbon residue in the gun chamber. This residue can interfere with the gun breech seal and possibly contaminate the breech window through which the laser is transmitted. Detailed experimental investigations revealed that these materials could be reliably ignited using 2–5 J of laser energy from a 3-ms laser pulse. Representative data is presented in Figures 2a and 2b.

3.2 <u>Laser Ignition of JA2 Propellant</u>. Ignition of condensed-phase media su solid propellants, explosives, and other energetic materials using pulsed-laser sources may afford numerous advantages over conventional chemical means used for the initiation of these materials. In particular, the ignition characteristics of these substances are not only affected by their chemical, physical, and thermal properties, but also by their optical properties (DeLuca et al. 1976).

Laser ignition of solid propellants can be conveniently categorized into two regimes (Harayama, Saito, and Iwama 1983). The first is self-sustaining ignition where the existence of a standing flame front results in complete combustion of the material subsequent to the removal of external heating by the laser radiation. Decomposed gases generated at the propellant surface diffuse rapidly into the gas phase through a steep thermal gradient. If the combustible gas concentration and surface temperature are sufficiently high, then self-sustaining combustion occurs. The second is non-self-sustaining ignition where the existence of a standing flame front is dependent upon heat flux input from the laser. Insufficient surface decomposition and low surface temperature combined with poor heat transfer between gas phase and condensed phase reactions extinguishes combustion if the laser radiation is terminated (Kashiwagi 1979). Determination of the experimental conditions which lead to self-sustaining laser-initiated combustion are the focus of these experiments.

Small quantities of propellants can indeed be ignited by single laser pulses, but heat transfer and subsequent flamespreading throughout the charge can be slow without the use of a distributed ignition system. For example, blackpowder and primer material are, relatively speaking, very energetic, have fast burn rates, fast gas generation rates, and produce hot particles which serve to spread the ignition stimulus throughout very quickly. Direct laser-based ignition of a series of propellants using the Nd:glass laser was

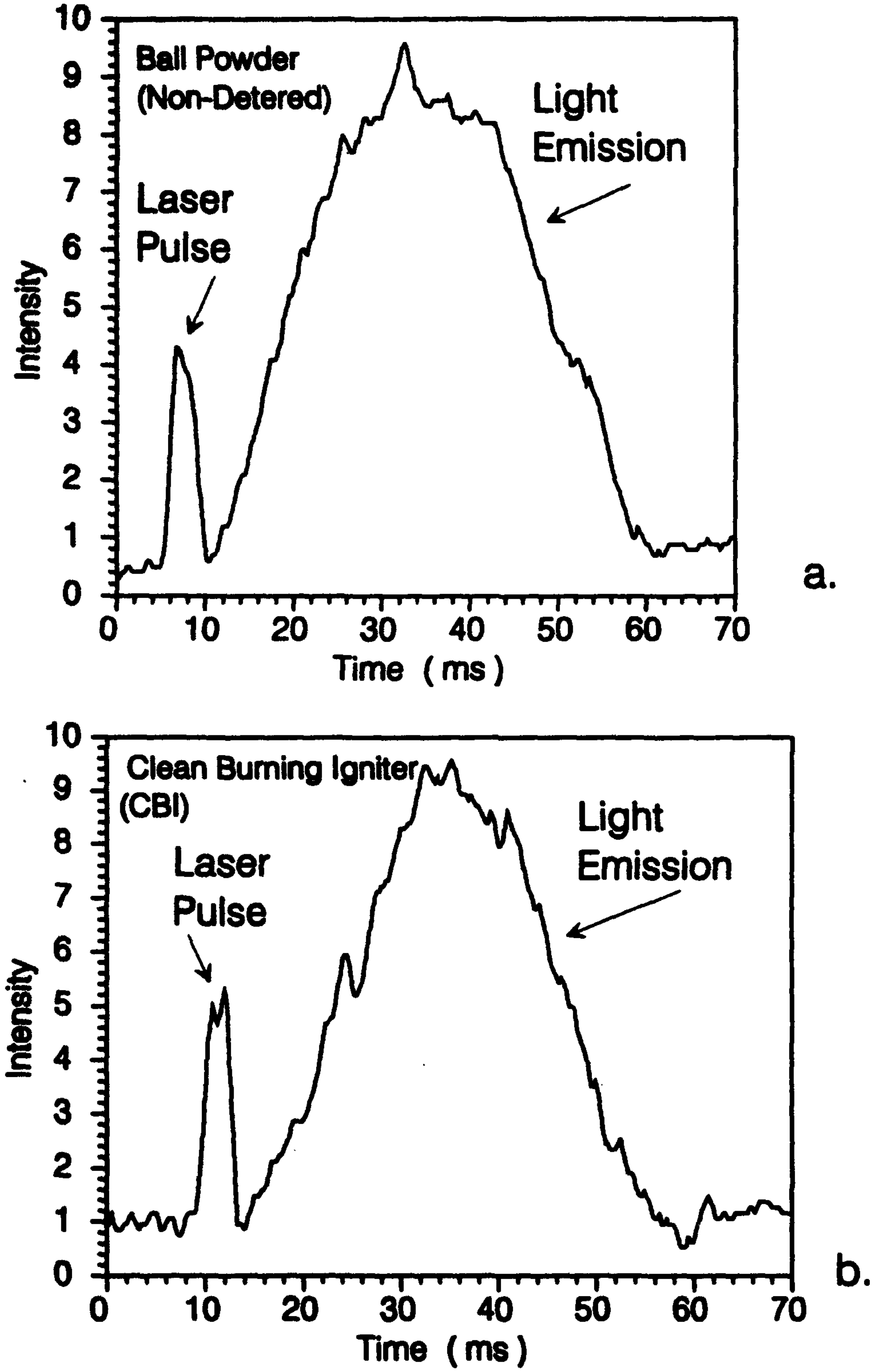

Figure 2. Representative laser ignition data for a) ball powder and b) clean burning igniter.

investigated. These include JA2, M30, LKL, LOVA, and HMX1. We chose to perform the bulk of the quantitative measurements on JA2, which is a well-known nitrocellulose-based propellant. An important consideration is the coupling of the laser energy into the propellant at the surface. Coatings on the propellant, such as graphite, greatly enhance the absorption of laser energy at 1.05 µm for samples which could not otherwise be ignited. Ignition is also enhanced when graphite is dispersed within the propellant formulation. An additional important consideration is the laser pulse duration. It was found that short laser pulses (nanosecond time scale) produce an intense light flash of ignited pyrolysis gases, however, sustained combustion of the bulk solid was not achieved after the laser pulse subsided. Apparently, the rate of energy input to the solid greatly exceeds the rate of thermal diffusion into the bulk sample such that "hot spots" are formed which results in surface ablation and ejection of material which inhibits sustained combustion. Longer laser pulses on the order of 3–10 ms, 5–10 J successfully ignited propellant samples in ambient air.

A deflagrating solid propellant sample of JA2 exhibits a complex flame structure consisting of several stages (Liiva, Fetherolf, and Litzinger 1991). The first stage involves condensed phase decomposition due to heat flux at the surface of the propellant. The second stage, called the "fizz zone," is the beginning of the gas phase reaction and is very thin (100–200 µm) at 1 atm of pressure. This zone is an important source of heat feedback to the propellant surface as well as gassification which sustains ignition when the radiant ignition source is removed. The third stage is the dark zone or non-luminous region above the surface between the solid-gas interface whose thickness is highly dependent on pressure (Miller and Kotlar 1986). The fourth and final stage is the luminous flame front whose appearance is dependent on ambient gas conditions and pressure. At pressures <1 atm, a luminous flame is not observed in an oxygen-free environment in a closed vessel. At high oxygen concentrations, the flame burns closer to the propellant surface than at lower oxygen content. For convenience, the bulk of our experiments were performed at atmospheric pressure and in air rather than a closed combustion chamber. Under these conditions, the laser-ignited propellant samples burned as a diffusion flame with an unlimited supply of oxygen.

Parametric investigations of JA2 ignition revealed similar trends in the ignition behavior as had been observed in blackpowder ignition. Laser ignition delays decreased linearly as the pulse width decreased and the ignition energy threshold decreased as the laser pulse width increased (Figure 3a). We also found that at constant laser pulse length, the ignition delay time decreased with increased laser energy. Laser interaction with the surface produces high concentrations of initial decomposition products which drops

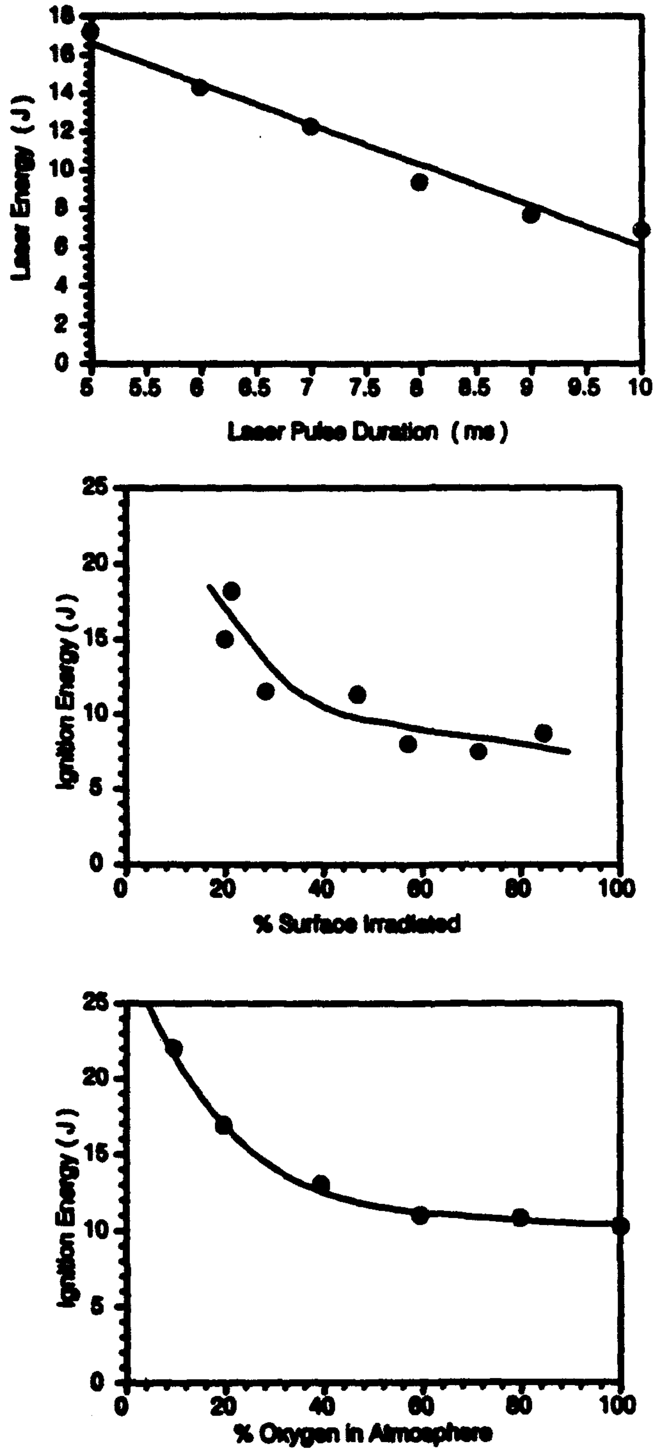

Figure 3. Results of quantitative laser ignition experiments on JA2 propellant.

off away from the surface. A laser-produced plume was detected at all ignition thresholds, regardless of the laser pulse width, and was accompanied by ejected particulates and blackbody radiation.

The important process in radiative ignition is the absorption of sufficient external radiation to heat the material near the surface above its decomposition temperature and release decomposition products. When radiant energy is incident upon the sample, most of the energy is absorbed by the sample at the surface and a portion is reflected by the surface. The fraction of incident radiation which is absorbed or reflected may be highly dependent of the laser wavelength and will be the subject of future investigations. Radiation that is absorbed by the sample converts to heat energy, and if diffusion of heat through the sample keeps pace with the rate of energy absorption, then thermal gradients among the ingredients will remain minimal and chemical decomposition will evolve spontaneously. When the energy absorption rate in the sample is much greater than the diffusion rate, intermolecular thermal gradients develop. Thermal gradients and hot spots develop that promote decomposition and/or reactions of sensitive ingredients (pyrolysis). Pyrolysis gases from the decomposed propellant surface rapidly diffuse into the gas phase and ignition occurs in the gas phase very close to the surface. The induction time for laser ignition to occur is highly sensitive to the area illuminated by the laser. We found that, in general, the induction time or ignition delay increased with decreased illuminated surface area (Dimitriou et al. 1989). The ignition delay for JA2 plotted as a function of the percent of the surface irradiated by the laser (at constant energy, 7 J) is shown in Figure 3b. The laser beam was gently focused using a 1-m lens and the samples were positioned to intersect the beam at different distances. As the sample is translated away from the lens towards the laser focus (at constant energy), the energy density increases, which tends to minimize the ignition delay. However, this effect is counteracted by the tendency for decreased percent surface irradiation to increase the ignition delay time such that from ~80% to 30% surface illumination, the ignition delay time remains fairly constant. At <30% surface illumination, the ignition delay time increases much more dramatically to the threshold (dotted line) where the sample ignites, but combustion is not sustained subsequent to the termination of the laser pulse.

Since the gas-phase reactions near the propellant surface during laser ignition with the ambient atmosphere may play an important role in the early stages of ignition (Liiva, Featherolf, and Litzinger 1991), we performed a series of experiments to determine the effect of molecular oxygen concentration on threshold for laser ignition. This was accomplished by determining the laser ignition threshold of JA2 propellant as a function of percent oxygen concentration in a plexiglass chamber which was purged with a mixture of oxygen and argon gas at constant pressure and volume. The ignition energy threshold increased slightly as the percent oxygen in the ambient atmosphere decreased from 100% to 40% (Figure 3c). At lower oxygen concentration, particularly <20%, the ignition energy threshold increased dramatically. This observation clearly indicates that chemical reactions between laser-produced pyrolysis gases with oxygen must promote chemical reactions which enhance thermal feedback to the propellant surface and reduce the energy required for ignition or increases the flame propagation rate during the early part of burning. It has been shown that increasing the amount of oxygen dissociation decreases the ignition delay time and increases the flame propagation rate during the early part of the burning in gas phase combustion, and that there are potential advantages to be gained from ignition by a combination of oxygen atoms and heat (Sloane 1983, 1985).

3.3 ATACS Simulator Testing. Preliminary testing of a two-piece, multipoint blackpowder igniter system is in progress. An important consideration is the optical access into the gun. Concepts where a small optical window is incorporated into the breech have been developed by the British and shown to be highly successful. The breech window must be composed of a material which will readily transmit the laser radiation and, in addition, withstand the high pressures encountered with large-caliber guns. A suitable breech window material made from aluminum oxide (sapphire) easily satisfies these requirements. Synthetic sapphire is routinely used in high-pressure, hostile environments. In addition to the requirements of the window for robustness and high transmissivity at the laser wavelenguns used, problems associated with contamination must be addressed. The breech window may well survive a single initiation, however, combustion products and particulates (debris) may contaminate the window and reduce the transmission of the laser beam in subsequent firings. Repeated firings may produce a degree of contamination wherein the transmitted laser energy is no longer sufficient for reliable ignition. Simple concepts have been developed, however, such that the breech window can be somewhat shielded from the combustion event and/or cleaned using a breech brush. It has been demonstrated that if the breech window is incorporated into a debris trap, then contamination can be minimized (i.e., the window does indeed become somewhat obscured by particulates, but a steady-state condition is achieved which inhibits further loss in transmission). ARL has proposed a unique double-window concept which may have important applications in the laser-based ignition of tank rounds.

As mentioned earlier, the incorporation of multicomponent ammunition in the propelling charge introduces interfaces which can interfere with reliable flamespreading characteristics in the combustion event. Interfaces which inhibit rapid flamespread within the propellant bed can lead to localized ignition which in turn may produce pressure differentials between the charge and projectile base. Pressure differentials can lead to oscillations which may result in catastrophic failure of the gun. Interior ballistics calculations performed at ARL have shown that simultaneous ignition of multicomponent ammunition such as the two-piece tank round can minimize localized combustion, enhance flamespreading characteristics, and minimize the probability of gun failure. The rear component of the two-piece tank ammunition contains mainly propellant and igniter material. The forward component contains propellant and the projectile. Both components are assembled and loaded mechanically. The ignition requirements for tank munitions are much more stringent than those of artillery guns. Ignition of both components must be achieved on a millisecond time scale. The ATACS round, unlike an artillery charge, utilizes a stub-case which makes an effective seal of the round to the breech. ARL has proposed an ignition concept for ATACS which utilizes a double window. The gun breech contains a sapphire window through which the laser beam is transmitted, however, in addition, the stubcase also contains a window. Combustion products may contaminate the stubcase window, but the breech window remains protected from this environment. The next ATACS round which is loaded contains a fresh window. The laser can be mounted on the breech or coupled to the breech using optical fibers. An optical fiber which is contained within the first component of the two-piece ammunition delivers a portion of the laser energy to a blackpowder igniter in the rear of the forward ammunition component. The optical fiber in the rear component can easily be contained in an igniter tube or combustible case which will facilitate loading of the propellant. ARL also proposes the use of tapered optical fibers to facilitate the transfer of the laser beam from the breech into the optical fiber contained in the rear component. The tapered fibers easily align with the input laser beam from the breech and can be designed to partially transmit a portion of the laser beam to both igniters in the front and rear components. The laser beam which exits at the front end of the rear component can easily pass through the mylar interface and strike the rear igniter in the forward component to achieve simultaneous ignition. Optical fiber networks can also be distributed within the charge to achieve multipoint ignition or to accommodate complex projectile geometries which may extend into the rear portion of the ammunition.

Subsequent to the laboratory testing of both the laser ignition of blackpowder and JA2 propellant, a simple single-point ignition system was tested in a 25-mm ballistics simulator in an indoor range. The simulator test setup is depicted in Figure 4a. A single laser pulse passed through a sapphire window and struck a blackpowder igniter. The simulator contained a grain of JA2 propellant and a bed of inert propellant. The pressure-time curve for the ignition event is shown in Figure 4b. The blackpowder ignited during the laser pulse, which in turn ignited the JA2 propellant grain. The loading density of the live propellant was low and, as a result, the total flamespreading time and pressure rise occurred over a

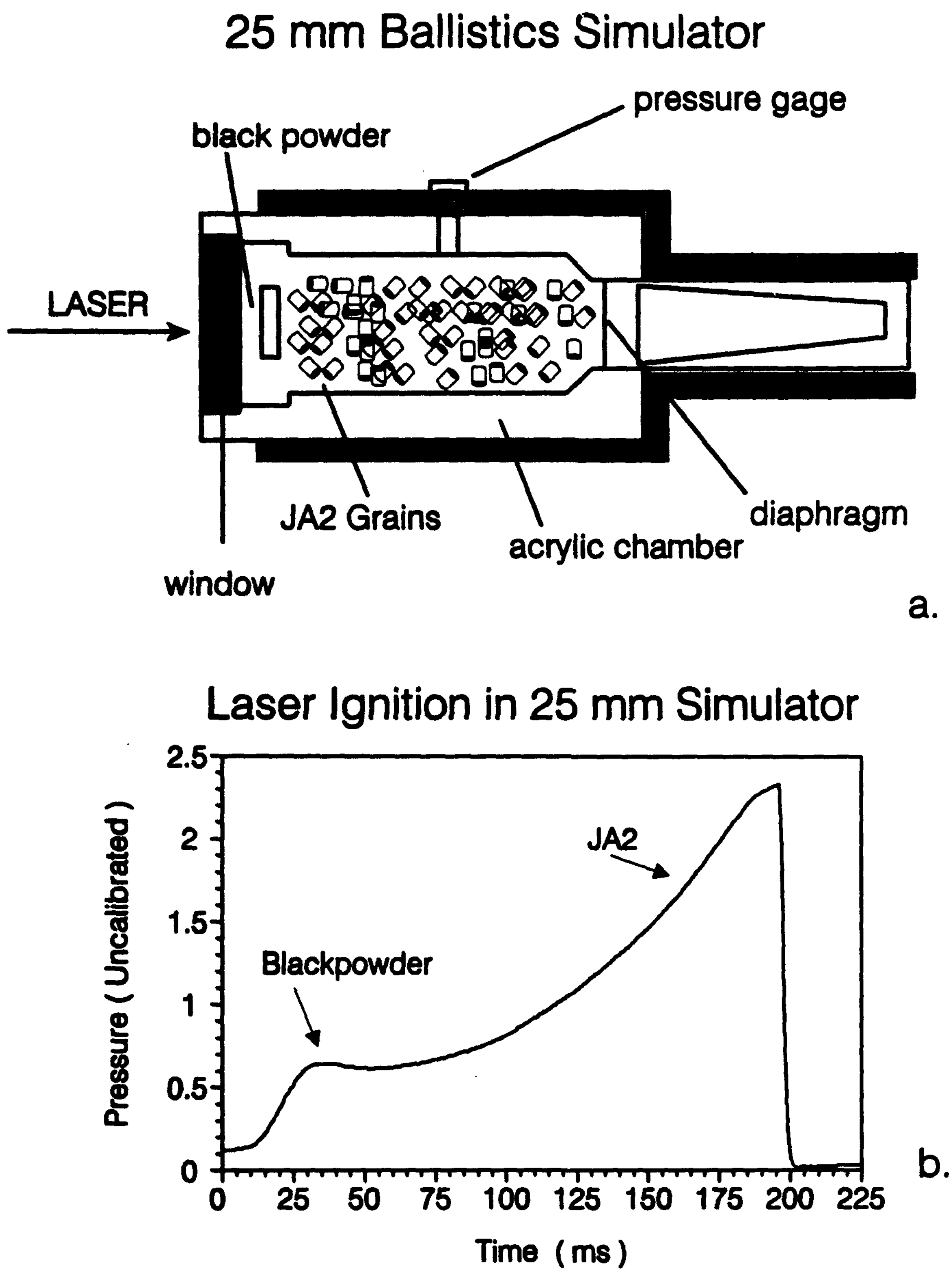

Figure 4. Schematic of 25-mm ballistics simulator and pressure-time curve for ignition in 25-mm simulator.

ca. 200-ms time scale. Nonetheless, the laser ignition system demonstrated the capability to successfully transfer the ignition stimulus to the propelling charge.

The blackpowder laser-based ignition system was then transferred to a 120-mm ballistics simulator which was setup in an ATACS two-piece ammunition configuration. The two-piece cartridge design has been the subject of recent detailed investigations (Chang and Robbins 1992). Prototype designs which utilize an igniter tube and combinations of stick and granular propellant have been varied to achieve simultaneous ignition of both components and acceptable flamespreading characteristics. The ignition technology developed within this work has been transferred to the current ATACS configuration with essentially little modification to the current design. In order to fully evaluate the ignition system concept and to investigate flamespreading, ignition point locations and timing between the ignition of both ammunition components the following two tests were conducted. The vented igniter tube was loaded with class 1 blackpowder and three optical fibers were inserted. The first fiber was positioned at the rear end of the tube and a second fiber terminated at the forward end of the tube. The third optical fiber was located within a booster at the end of the igniter tube which contained Class 5 blackpowder. The igniter tube was loaded into the first ammunition component, which was packed with inert granular JA2 propellant. The second ammunition component contained a blackpowder basepad (Class 5), inert stick JA2 propellant, and the projectile. The charge was loaded into a transparent plexiglass tube which contained two pressure gauges (Figure 5a). The configuration of the second test charge was similar to the first except that the igniter tube was packed with Class 3 blackpowder and a small bag of Class 5 blackpowder was attached to the end of each optical fiber (Figure 5b). The laser-based ATACS ignition configuration has been designed to simultaneously ignite both components. All optical elements have been located within the igniter tube to facilitate propellant loading. The first two fibers within the igniter tube are designed to ignite the blackpowder and subsequently the propellant. The third fiber is designed to ignite a booster which essentially ruptures the interface between both components and subsequently ignites the forward ammunition component.

The overall simulator test set-up (Figure 6a) used in this work is located at the Propulsion and Flight Division's Large-Caliber Gun Testing Facility. Two high-speed cameras recorded flamespreading within the simulator. The laser system control was modified to incorporate several safety features. A 100-ft external interlock to the power supply was supplied to the firing control room. An external firing line was also run from the laser power supply to the master fire control. An optical fiber network which consisted of three 125-ft fibers was delivered to the simulator. Each fiber was equipped with an SMA connector

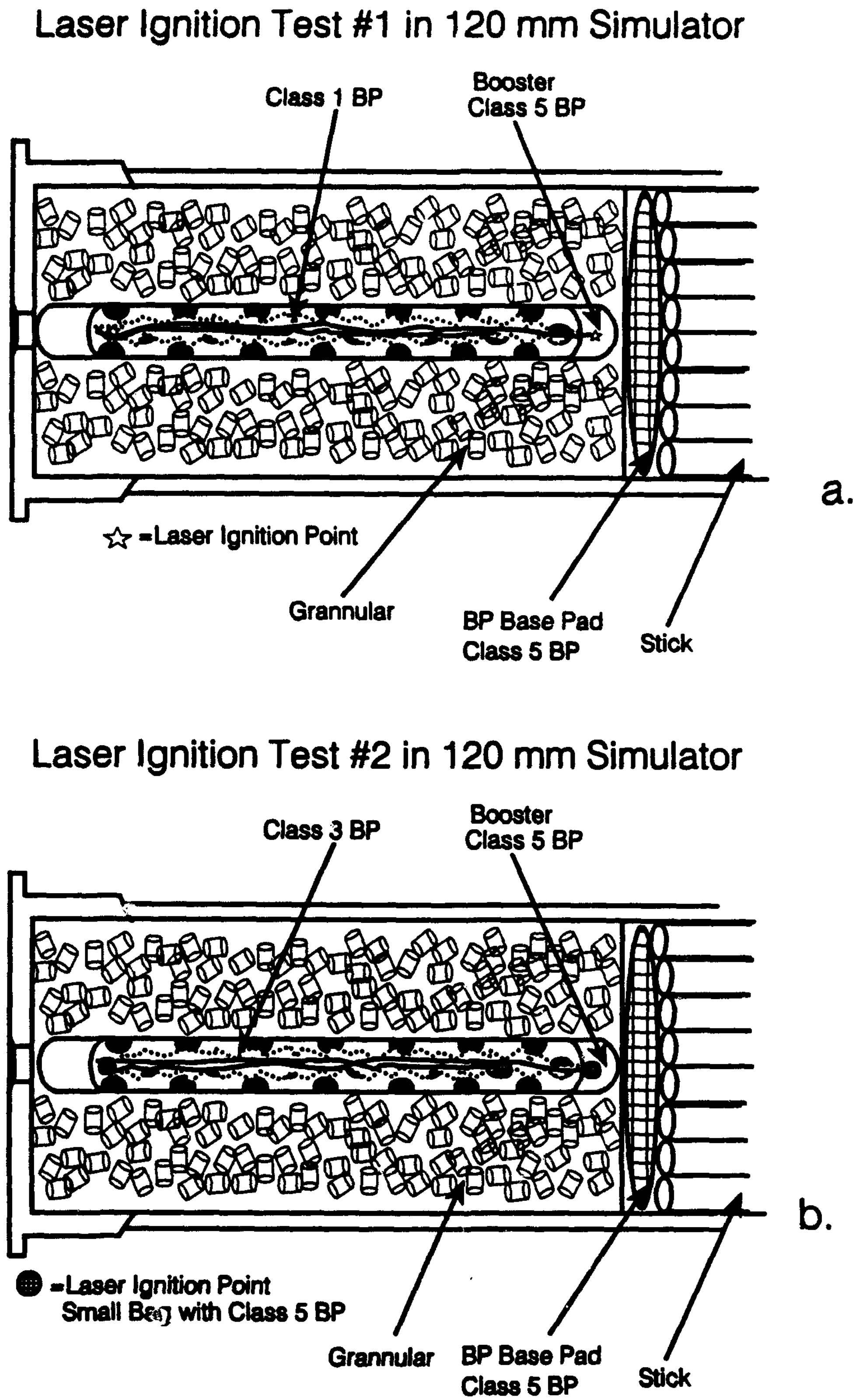

Figure 5. ATACS laser ignition configurations for a) test no. 1 and b) test no. 2.

and connector bushing which served as a disrupt point for the laser beam for safety. This feature allowed for the laser to be adjusted and fired without being directly connected to the simulator.

The firing sequence for the simulator testing proceeded as follows. The test charge configuration was assembled and loaded into the simulator while the laser was aligned for optimum transmission, then the laser was completely shut-down. At this point the optical fibers from the simulator and laser were disconnected. The laser system was repeatedly test fired from the control room to insure proper functionality. Once the simulator was ready, the range area was cleared of all personnel. The SMA connector bushings were then used to connect the optical fibers from the laser to the simulator which was located behind a barricade. A key interlock which supplied power to the laser power supply was turned on, then a second interlock was switched on at the power supply. Inside the control room, a third laser power supply interlock was turned on which enabled the laser flashlamp pulse-forming network to charge. At this point in time, the laser must then be fired within 45 seconds; otherwise a fourth interlock will shut the laser system down. The final firing signal (TTL) was then delivered to the laser.

The pressure time data from both simulator tests are given in Figure 6b. High-speed film data from the event was also recorded. In test no. 1, approximately 1.0 J of laser energy (from a single 10-ms-long laser pulse) was delivered through each optical fiber to the charge. Ignition of the blackpowder occurred during the laser pulse as anticipated. However, a comparison of the high-speed film data and pressure-time curve showed that both components did not ignite within less than the desired 1-ms time frame. The film data showed that the ignition of the forward component preceded that of the rear component. Further consideration of this data and laboratory testing have shown that since the laser light did not strike identical samples of blackpowder (the classifications were different), the relative ignition delay between the two components could be attributed to two variables. The diameters of Class 1 blackpowder granules in the igniter tube are large (5–10 mm) compared to the powder-like consistency of the Class 5 blackpowder contained within the booster and basepad. Therefore, there are necessarily differences in both flamespreading and orientation effects between the terminal ends of the fiber and the proximity of the grains near the fiber. In order to minimize these uncontrolled variables, it was decided to attach a sensitizer at the end of each fiber which contained the very fine Class 5 blackpowder. The pressure time data and high-speed film data confirmed these contentions. In test no. 2, the blackpowder ignited during the laser pulse and, in addition, both the forward and rear ammunition components ignited within 0.6 ms of each other. The pressurization was much more expedient and flamespreading was

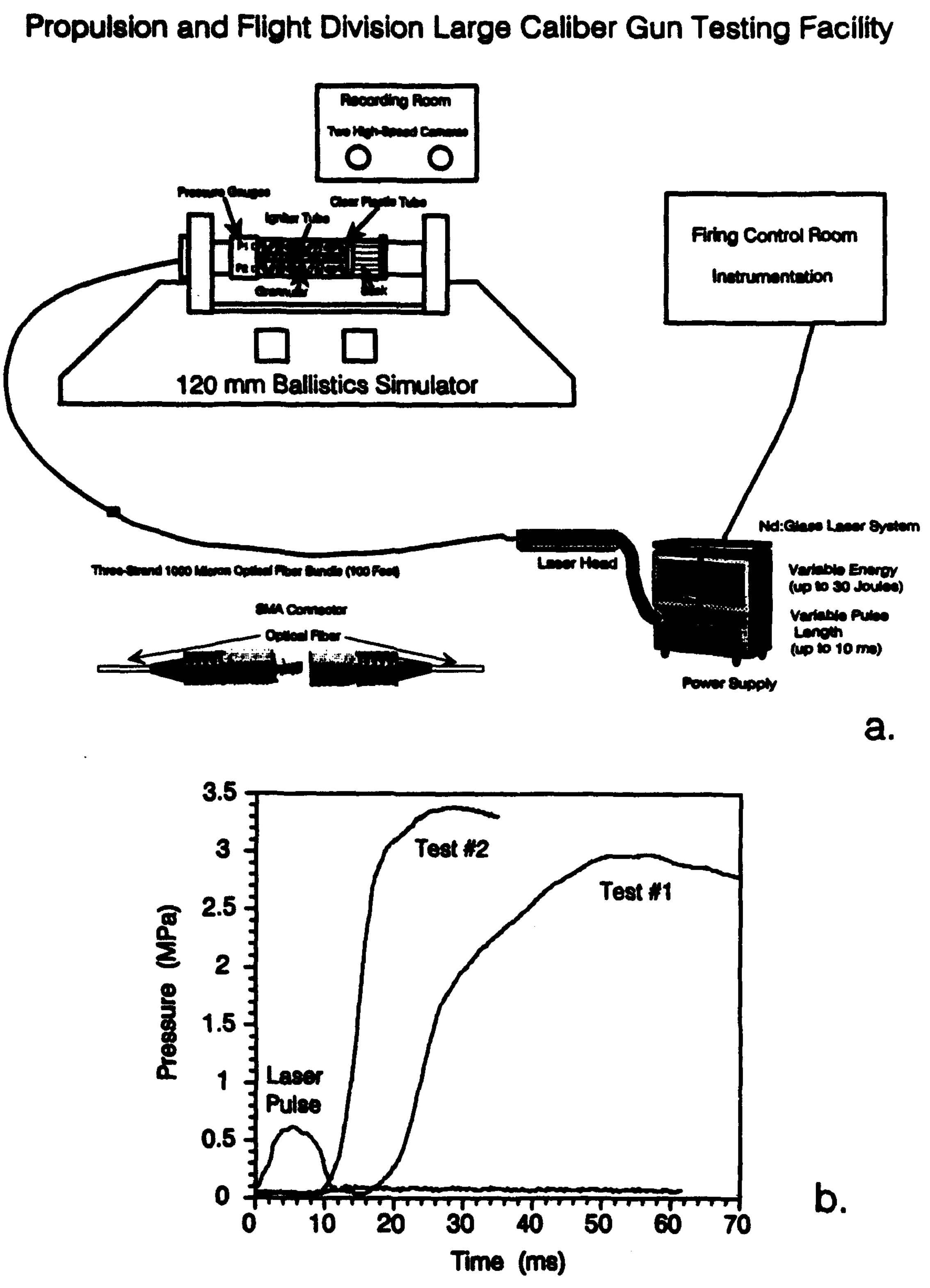

Figure 6. a) Ballistics simulator test setup and b) pressure-time curves from laser ignition in ATACS configuration.

complete. Future testing will be aimed at optimizing the number of ignition point locations and then firing with live propellant.

4. CONCLUSION

The preliminary results from the testing of a laser-based ignition system for ATACS have been described. Parametric investigations of the ignition train optical components and igniter material such as blackpowder, ball powder, CBI, and JA2 propellant were given. Full-scale simulator testing on the ATACS ignition system has demonstrated near simultaneous ignition of the components in two-piece ammunition. The development of laser-based ignition systems for large-caliber guns such as ATACS has the potential to solve problems associated with reliable and reproducible flamespreading characteristics within propellant beds. The recent advances in gun propulsion systems which utilize multicomponent ammunition, autoloading devices for projectiles, charges, and primers place new constraints on the ignition train. In addition, insensitive munition requirements for future gun systems may require alternate or non-conventional ignition sources to be implemented. As a result, laser-based ignition systems may prove to be a viable initiation source for these munitions. Laser energy distributed through optical fibers embedded in a propellant bed cannot only ensure simultaneous ignition of the charge, but also reduce overall system vulnerability from the elimination of all primer and igniter material from the munition. Laser ignition systems may also have an impact on gun performance through temperature compensating and/or programmed delivery of laser energy through optical fibers. New developments in optical fiber material may produce energetic and consumable fibers which leave no residue in gun systems and, in addition, enhance ignition.

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